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RESEARCH DEPARTMENT

Some investigations into the performance of the C. P. S. Emitron television camera tube

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THE BRITISH BROADCASTING CORPORATION
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RESEARCH DEPARTMENT

SOME INVESTIGATIONS INTO THE PERFORMANCE OF THE C.P.S. EMITRON TELEVISION CAMERA TUBE

Report No. T-118

(1963/63)

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SUMMARY

This report describes a series of experiments carried out in order to determine the behaviour of a C.P.S. Emitron television camera tube in the operating conditions encountered in image-transfer standards converters. Some previously undetected aspects of the storage characteristics are described, and beam pulling has been considered in some detail. Finally, the results are related to the behaviour of an image-transfer converter using this type of camera tube.

1. INTRODUCTION

Two forms of the C.P.S. Emitron camera tube have been in regular use for the generation of high quality television pictures for approximately 15 years. An improved version, known as the tri-alkali C.P.S. Emitron, with increased sensitivity and contrast range is a relatively recent development of the tube and is the type considered here. Detailed descriptions of both types of tube and their modes of operation have been given elsewhere.[1,2]

In order to obtain a better understanding of the operation of the C.P.S. Emitron in a standards converter,[3] it has been necessary to investigate certain of its various characteristics under the conditions encountered in this application. The information obtained from the investigations could also provide guidance in selecting the most suitable type of camera tube to use in image-transfer converters.

The investigations carried out fall into a number of groups covering those characteristics of the C.P.S. Emitron most likely to influence its performance in a converter, namely:

1. Erasure
2. Storage
3. Resolution
4. Reciprocity failure
5. Beam pulling
6. Other effects such as flare, veiling glare, ion fog, etc.

One of the most important characteristics in the standards conversion process is that of storage. The failure of the scanning beam to erase the camera target during one field scan results in a 'lag' signal which has a similar effect on the converted picture to that due to a display-tube phosphor with a long-time constant, apparently decreasing the sharpness of moving images but, at the same time, reducing flicker modulation.[4]

It is necessary for the charge image on the camera target, representing the picture to be converted, to be retained for at least a field period; otherwise, information is lost and the performance of the converter will suffer. When converting between standards having the same field frequencies, inefficient camera-tube storage causes the phase relationship between the field-scan pulses of the two standards to be critical; in the case of conversion between standards having different field frequencies, inefficient storage results in an increased flicker modulation of the signal at a frequency which is the difference between the two field frequencies. The storage characteristic of the camera tube also determines to some extent the decay characteristics required of the display-tube phosphor; storage losses can be partially compensated by an increased phosphor time constant, the use of which, however, increases the 'lag' signals or blurring associated with moving images. With certain types of camera tube, including the C.P.S. Emitron, the relationship between the camera-storage and phosphor-decay characteristics also affects the ratio of converted signal to unconverted signal (or photo-signal),[4] a longer phosphor decay time tending to improve this ratio.

Poor vertical resolution, due to an excessive beam aperture, prevents the recovery of independent signals on successive interlaced field scans and reduces the effective exposure time of the camera. Loss of resolution due to target leakage results in a greater loss of picture definition when converting to a standard with a higher field frequency than vice versa.

Reciprocity failure of the camera target, like inefficient storage, results in a variation of the converted signal amplitude as a function of the phase difference (or time interval) between 'writing' and 'reading'; the effect, therefore, contributes to flicker modulation when converting between standards having different field frequencies. Excessive beam pulling or bending, in addition to impairing the sharpness of the edges of bright images, is likely to result in a reduction of the small-area contrast in the converted signal.

Excessive beam pulling can also impose an unduly low limit on the maximum brightness of the image at the camera-tube sensitive surface and thus limit the signal-to-noise ratio at the camera output.

Optical reflections taking place inside the camera tube can cause flare and veiling glare; these two effects have also been described as a.c. and d.c. flare[5] respectively. The former, which is more particularly associated with reflections from the camera-tube face plate, reduces the sharpness of image boundaries. The latter, which is a result of general light reflection and scatter, produces a small component in the camera output signal proportional to the mean image brightness and reduces the contrast ratio of the image.

A further effect, caused by positive ions landing on the target, also causes a loss of contrast and is a function of beam current; the effect is described in this report as 'ion-fogging'.

2. MEASUREMENT OF CHARACTERISTICS

2.1. General

In all the experiments to be described, normal camera operating conditions were preserved, except where stated otherwise, and care was taken to exclude stray light from the camera. White signal level was equivalent to a video-signal output of 0·7 V peak from the camera control unit (a current of approximately 0·12 μA in the camera-target load resistance). Wherever possible, a suitable low-pass filter was inserted in the output of the camera in order to minimize the effects of random noise on the measurements.

2.2. Erasure

A preliminary experiment relating to the erasure characteristics of the C.P.S. Emitron was carried out in order to obtain measurements of:

(i) the extent to which one field scan of the target influenced the charge available for the successive interlaced scan;

(ii) the target 'discharge lag';*

(iii) sensitivity variations over the target area.

The apparatus was arranged as shown in Fig. 1. A short persistence (P16 phosphor) tube was arranged to display an interlaced synchronized raster having a vertical line scan and a horizontal field scan. A brightening pulse for the display tube, repeated at half field-frequency (i.e., picture frequency) and having a duration of approximately 400 μs, was produced by the line selector and pulse generator. The resulting image focused on the camera target consisted of a bright stripe, extending vertically over the target, which could be positioned horizontally by means of the line selector.

The sync-pulse generator associated with the scanning circuits of the C.P.S. Emitron was modified to provide either 405-line interlaced scanning or 204-line sequential scanning and was 'locked to the mains' via a goniometer; this enabled the relative phasing between the field scans of the camera tube and display tube to be varied.

By adjusting the goniometer, the camera exposure was phased to occur during the camera field-blanking period, ensuring that reading did not commence until exposure was completed and that photo-pulse[4] signals would be eliminated by field blanking from the output video waveform. Measurements of the camera output signal from 25 positions on the target were then taken for the first and second scans following exposure; the display brightness was adjusted to produce a maximum signal equal to white level. Further measurements were made, on the one hand, with reduced camera-tube illumination and normal beam current, and then, on the other hand, with normal illumination and reduced camera-tube beam current.

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* This describes the failure of the scanning beam completely to discharge one picture-element area of the target in one scan. 1,6

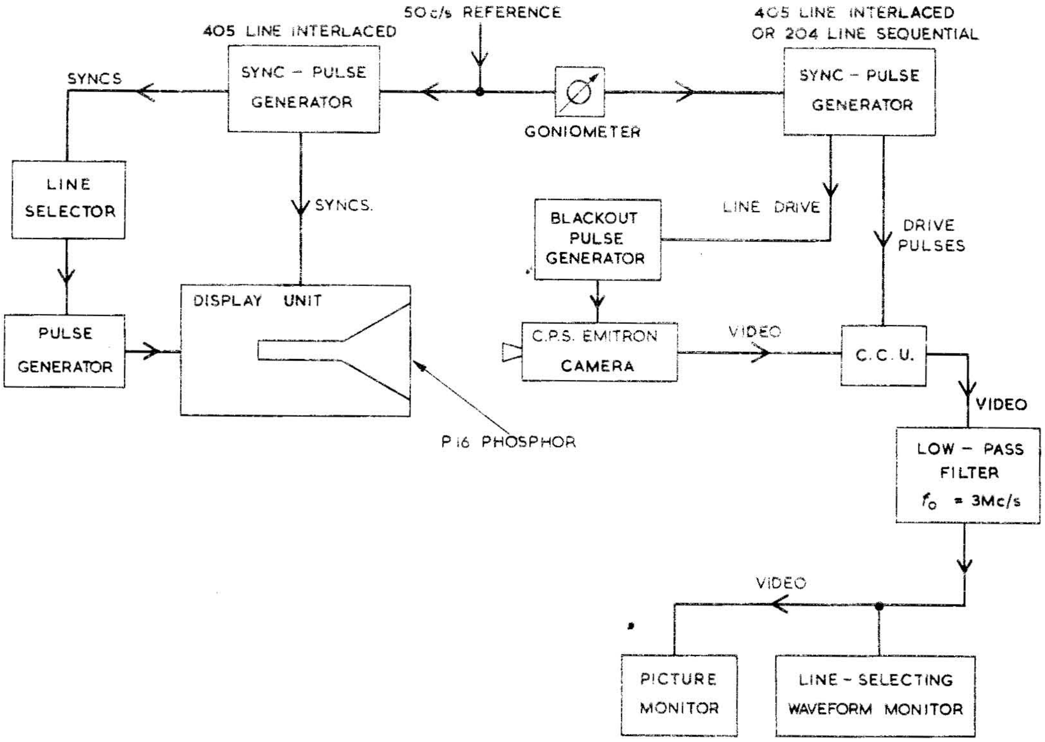


Fig. 1 - Apparatus used for measurement of erasure characteristics

It was anticipated that with good resolution and storage, the camera output during odd and even scans, for 405-line interlaced scanning, would be approximately equal. This was not the case as is seen in Fig. 2, which shows, in three dimensional form, the relative output-signal levels produced by the first and second scans from the 25 positions explored on the target.

The ratio of the output produced during the second scan to that produced during the first is seen to vary, for different points on the target, about a mean value of approximately 0·3. Corresponding measurements with reduced illumination produced approximately similar results; in each case the majority of the target information was erased during the first reading scan after exposure.

The only significant effect produced by variations of beam current was seen when the current was reduced to an amount just sufficient to ensure target-potential stability. The first-scan output level then decreased and there was a corresponding increase in second-scan output so that both scans now produced signals of similar magnitude; this was almost certainly due to insufficient current being available for erasure requirements during the first scan, leaving an increased proportion of the target information for erasure during the following scan.

Using a constant illumination level, considerable differences in camera output magnitude for various positions on the target can be seen in Fig. 2. These differences are thought to be due to variations of target sensitivity, beam focus and alignment over the target surface combined with any effects due to non-uniform storage characteristics.

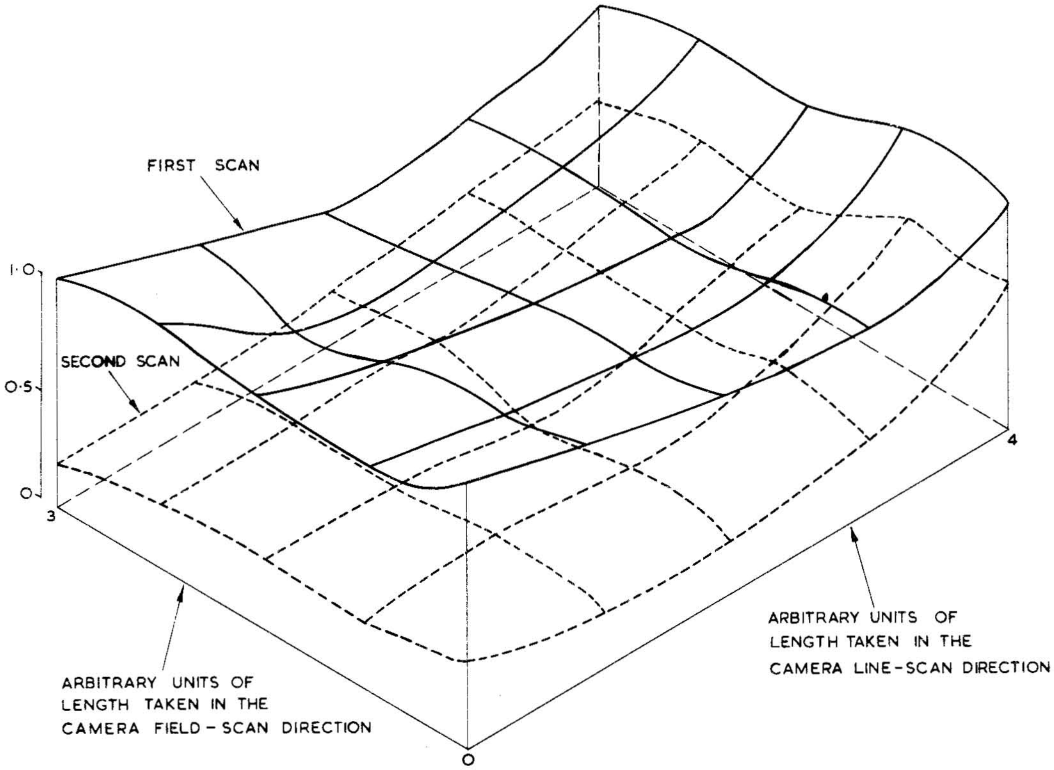


Fig. 2 - First and second scan outputs for single exposure of 400 µs during camera field blanking-scanning 405/50 interlaced

2.2.1. Interlaced and Sequential Scanning

Using the same experimental arrangement, a further series of measurements was then made using 204-line sequential scanning of the camera target.

A comparison of these results with those obtained previously showed that there was no significant difference between interlaced and sequential scanning from this point of view, the ratio of the output from scan 2 to that from scan 1 remaining approximately the same in both cases. Thus it would appear that lack of vertical resolution prevented the recovery of independent signals on the second scan of the 405-line interlaced raster. In both cases, the second scan collected discharge-lag signals remaining after the first scan but, in addition, received contributions from any previously undischarged target strips remaining between the areas covered by the first scan; in the case of sequential scanning, the beam was pulled towards them so as to produce an 'interlaced' second scan. Consequently, it was difficult to measure discharge lag in this way.

2.2.2. Number of Scanning Lines

At this stage, it was obvious that, in the conditions of the experiment, the target charge was substantially removed by the first scan, following exposure. In an attempt to recover independent signals from both the odd and even fields of an interlaced scan, a further series of measurements was made with the number of scanning lines per field considerably reduced. By inhibiting the camera beam-current for two out of every three lines (using a synchronized beam-blackout generator) and by increasing the camera field-scan amplitude, the effective number of scanning lines was progressively reduced to approximately 25 per field; successive scans could be either interlaced or sequential.

As the number of scanning lines was reduced, thus increasing the spacing between lines on the target, the second-scan output increased until a ratio of output from scan 2 to that from scan 1 of 0·95 was reached with only 25 lines per field. The results are illustrated in the diagrams shown in Fig. 3. Similar results were obtained with both interlaced and sequential scanning patterns, an effect that can only be explained by the beam being pulled towards, and erasing, unscanned charged areas on the target. This theory was further supported by the fact that if the stripe image was removed, when using a small number of scanning lines, very considerable discharge-lag signals were produced. Measurements showed that the camera output did not fall to 20% of maximum until 6 fields had been scanned after exposure, and was still 2% after 10 s (i.e., 500 fields).

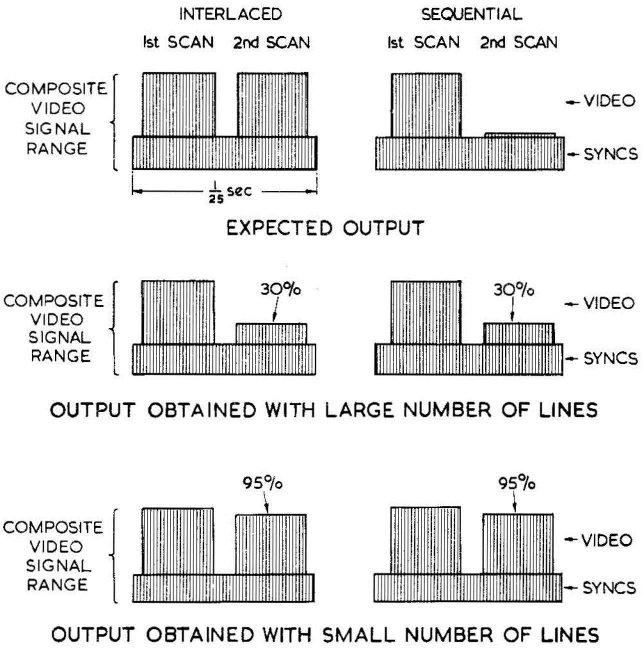

INTERLACED
1st SCAN
2nd SCAN
SEQUENTIAL
1st SCAN
2nd SCAN
COMPOSITE VIDEO SIGNAL RANGE
VIDEO
SYNCS
1/25 sec
EXPECTED OUTPUT
30%
30%
OUTPUT OBTAINED WITH LARGE NUMBER OF LINES
95%
95%
OUTPUT OBTAINED WITH SMALL NUMBER OF LINES

Fig. 3 - First and second camera scan outputs with different line spacings

2.2.3. Crossover Period

When the C.P.S. Emitron is used in conjunction with a display cathode-ray tube for conversion between standards having different field frequencies, the interval between writing and reading varies cyclically from zero to one field period. This means that, during a reading scan, the camera beam suddenly passes from information that has just been written on the target to information that has been stored for some time, or vice versa.

While the apparatus was set up in a suitable form, it was decided to examine the camera output during such a 'crossover' period. The display scanning was rearranged so that the field scan was vertical but reversed with respect to normal operation; the line scan was removed. The brightening pulse was removed and the cathode-ray tube beam current adjusted so that a display consisting of a single bright vertical line was produced with a brightness corresponding to white. Isochronous field scans were used but phased so that the transition from information stored for 20 ms to information just written occurred near the centre of the raster; the total photocurrent at the camera-tube target at this time was steady and had no effect on the output signal.

The output waveform is shown in Fig. 4 and it is seen that, a few lines prior to the crossover, the output decreased, then rose abruptly to a higher level immediately after crossover, and finally returned to normal during the next few lines. The disturbance was relatively small, lasting less than 1 ms and had an excursion equal to 15% of the signal corresponding to white.

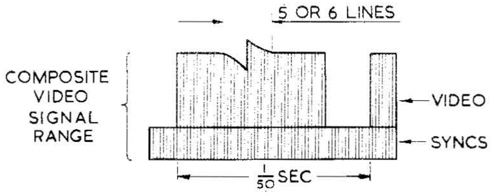


Fig. 4 - Camera output during 'crossover' period

A possible explanation of this effect is that, in the vicinity of the charge pattern being written, the camera beam is at first repelled by the negative field produced by electrons leaving the mosaic and, therefore, the output signal falls; when the camera scanning spot is in very close proximity to the edge of the newly-charged target area, it is attracted and thus accelerates into the newly-written area, thus increasing the output, until normal scanning velocity is finally resumed.

These early experiments demonstrated the importance of beam pulling as one factor determining the behaviour of the tube, and this effect was studied in more detail in later experiments.

2.3. Storage Characteristics

In this experiment a small area of the target was illuminated for a brief period and then scanned by the beam after a varying interval; the target was scanned by a 220-line sequential raster and the beam defocused in order to ensure that maximum target discharge occurred during the first reading scan following writing.

A block schematic diagram of the apparatus is shown in Fig. 5. The display again consisted of a vertical stripe, but for this experiment a mask on the display-tube face allowed the camera to 'see' only a section of the stripe as a small square. An 'eight-to-one' counter inserted in the sync-pulse feed to the display-tube brightening pulse generator increased the interval between camera exposures to 16 field periods (320 ms). The sync-pulses, at one sixteenth of field frequency, were used to initiate a camera-blackout pulse of adjustable duration and also to trigger the time base of the measuring oscilloscope.

The camera blackout-pulse generator permitted the interval between writing and reading to be varied from one to twelve field periods, in steps of one field period; delays including fractions of a field-period were obtained by adjusting the relative phasing of the two trains of field pulses.

With the display brightness set to give a standard camera output when reading immediately followed writing, the camera output was measured with various intervals between writing and reading. Further measurements were then made with different illumination levels and in two other positions of the patch on the camera-tube target; the measurements were made with various amounts of camera-tube beam current and with both interlaced and sequential scans. Finally, the series of measurements was repeated using another C.P.S. Emitron of the same type.

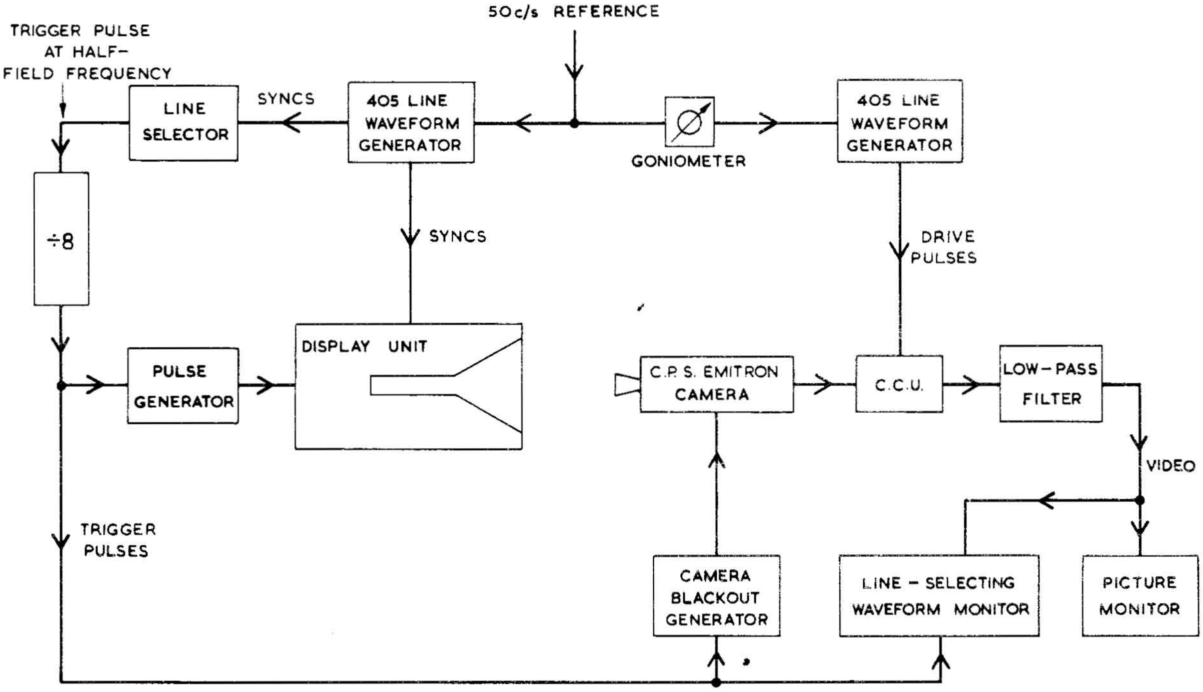


Fig. 5 - Apparatus used for measurement of C.P.S. Emitron storage characteristics

In all cases the signal 'read off' the target, after a storage period of two fields, was approximately 10% smaller than the value obtained with no delay between writing and reading. With a delay of more than two field periods, no further decrease in signal amplitude was noticed; the maximum storage period investigated was 12 field periods. It was also noticed that the second and succeeding scan outputs showed a slight increase in signal amplitude as the interval between writing and reading was increased. However, this increase in signal did not equal the loss in first-scan output over the same storage period. These effects are shown diagrammatically in Figs. 6 and 7. Variations of beam current produced no significant change in these results, except when the beam current was insufficient for target requirements during the first scan; this caused the second-scan output to increase as described in Section 2.2.

No immediate explanation of this storage loss was available, and, after making sure that the apparatus was in no way responsible for these effects, further experiments were then conducted in an attempt to establish the cause. The first two of these experiments yielded very little useful information and are only mentioned briefly here.

2.3.1. Storage with Various Exposure Times

For various exposure times, ranging from 200 μs to 40 ms, with the illumination adjusted to produce approximately the same output signal, no significant differences were noticed in the storage characteristics, the first- and second-scan output signals changing in much the same way as in the previous experiment.

2.3.2. Charge 'Spreading'

In this test, the whole target area was illuminated briefly, using a Stroboflash in place of the display cathode-ray tube, and the camera output signal was measured after various storage intervals; again the same results were observed for both the first and second scans. Thus, the possibility of the charge spreading laterally from a small image area to the surrounding unexposed target areas, owing to poor mosaic insulation, was eliminated. The possibility of charge leaking to the mosaic insulation was then considered.

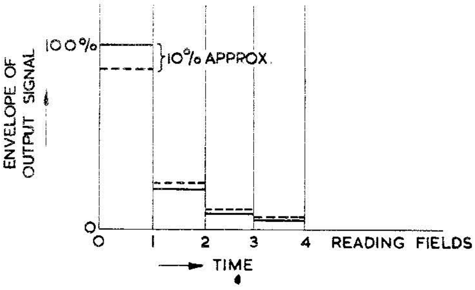


Fig. 6 - Camera tube output as a function of time interval before reading, showing decrease in first scan output and increase in second scan output

—— Reading commences immediately after writing

---- Reading commences at least 1½ field periods after writing

2.3.3. C.P.S. Emitron with High Target Insulation

A C.P.S. Emitron has the property that a negative version of the output signal caused by a bright image is obtained when the original image is removed and the mosaic then illuminated uniformly. This 'photographic' effect is due to negative charge that is built up on the insulating strips between the mosaic elements and is enhanced if the insulation resistance of the target is very high; in the normal C.P.S. Emitron, this is avoided by caesiating the target late in the manufacturing process.

It was thought that a tube having high target insulation, when subjected to the same test as described in Section 2.3.2., would indicate whether the apparent loss in target storage with reading delay was due to lateral spreading of the charge to the insulated areas between the mosaic elements. The previous experiment was, therefore, repeated with a non-caesiated C.P.S. Emitron.

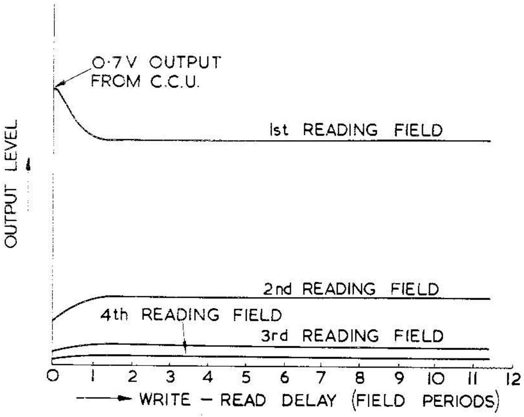


Fig. 7 - Camera output as a function of storage time

In this case, a 10% fall in first-scan output was observed after a reading delay about twice as long as that required when using a standard tube, while the second-scan output signals were very similar to those obtained with a standard tube. It appeared, therefore, that the nett loss of signal was less with a photographic C.P.S. Emitron. Part of the storage-loss might, therefore, have been caused by charge leakage into the insulated areas between the mosaic elements, this effect being less in the tube having the higher target insulation.

It was then suggested that the remainder of the storage losses were due to dielectric hysteresis, part of the positive charge on the target surface migrating into the target dielectric and reappearing after the majority of the surface charge had been removed by the first scan. This effect would be similar to the failure of a charged capacitor to deliver all its stored energy in one brief discharge, a residue of the original charge appearing a short interval after the discharge.

2.3.4. Dielectric Hysteresis

In order to test this theory, it was decided to repeat the test described in Section 2.3.2., but to delay the second and subsequent reading field scans by different intervals; this would allow any charge that had migrated into the dielectric to return to the surface and to be discharged by the scanning beam. The second-scan delay would be additional to the delay between exposure and the first reading scan.

The generator producing the auxiliary camera-blackout pulses was modified in order to provide the necessary combination of pulses (i.e., to permit variable delay between exposure and the first reading scan together with a further variable delay between the first reading scan and subsequent reading scans). In all other respects, the apparatus was operated as previously outlined; the whole target was illuminated briefly by the Stroboflash every 16 fields and the target was scanned by a 220-line sequential defocused raster.

The camera output was observed during the first reading field immediately following exposure and during subsequent reading fields, delayed with respect to the first by intervals of up to five field periods; this procedure was then repeated with increasing delay between exposure and the first reading field.

A non-caesiated C.P.S. Emitron was then substituted for the normal tube and the experiment repeated.

It was immediately seen that a delay between the first and subsequent reading scans enabled a larger signal than had been obtained in previous experiments to be recovered during later scans; this could have been the result of charge that had migrated into the target dielectric having a longer period in which to become available for discharge. When, for example, the first scan was delayed with respect to exposure by two fields and the second scan by a further five fields, the second-scan output increased by 25% above the amount obtained with no delay between the first and second scans. This effect is shown clearly in the oscillograms of Fig. 8; these were obtained using the photographic tube, although similar effects were observed with a standard tube. An explanation of this behaviour could be that, in delaying the first scan, more charge was able to migrate into the target, thus causing an increased amount of charge to be available for the delayed second scan.

Despite the increased output obtained from delayed second scans, it appeared that, during the first few scans, there was a nett loss in the total measurable signal when the first scan was delayed significantly with respect to the exposure. Examination of Fig. 9, which compares the storage behaviour of a normal and a photographic tube, indicates that storage losses appear to result from a combination of dielectric hysteresis loss which is to a large extent recoverable, and loss due to leakage to mosaic interstices which is not recoverable.

2.3.5. Effect of Stabilizing-Mesh Potential

It was thought that if migration of positive charge were taking place during the storage period, it might be possible to influence the effect by the application of a negative potential to the stabilizing mesh that is positioned close to the target, and thus retain the charge on the target surface. The previous experiment was therefore repeated in such conditions.

Although the stabilizing-mesh potential was varied from its normal value of +10 V to -40 V during the storage period, no changes were seen in the storage characteristics.

2.3.6. Effect of Operating Temperature

In order to determine the effect of target temperature upon the storage characteristics, the camera-tube cooling blower was fitted with a small heater and the sensing element of an electrical thermometer positioned near the target in the C.P.S. Emitron. Measurements of the camera output were then made with different storage periods and tube temperatures.

The effect of a temperature increase from 20°C to 34°C was to approximately double the losses suffered by the first-scan output; the second-scan reading field showed very little change. This would suggest that, at higher temperatures, dielectric hysteresis was unaffected, but charge leakage was aggravated; an increase in temperature would reduce the resistivity of the glass base on which the target is formed.

Thus, the storage experiments showed that, with a standard C.P.S. Emitron, a signal loss of some 10% occurs during the first two fields of storage, much of this loss being due to target dielectric hysteresis and being recoverable during subsequent scans. The only operating condition appearing to affect the storage characteristic is the temperature of the camera-tube target.

C.P.S. Emitron, defocused beam, whole target illuminated, 60 μs flash 16 fields

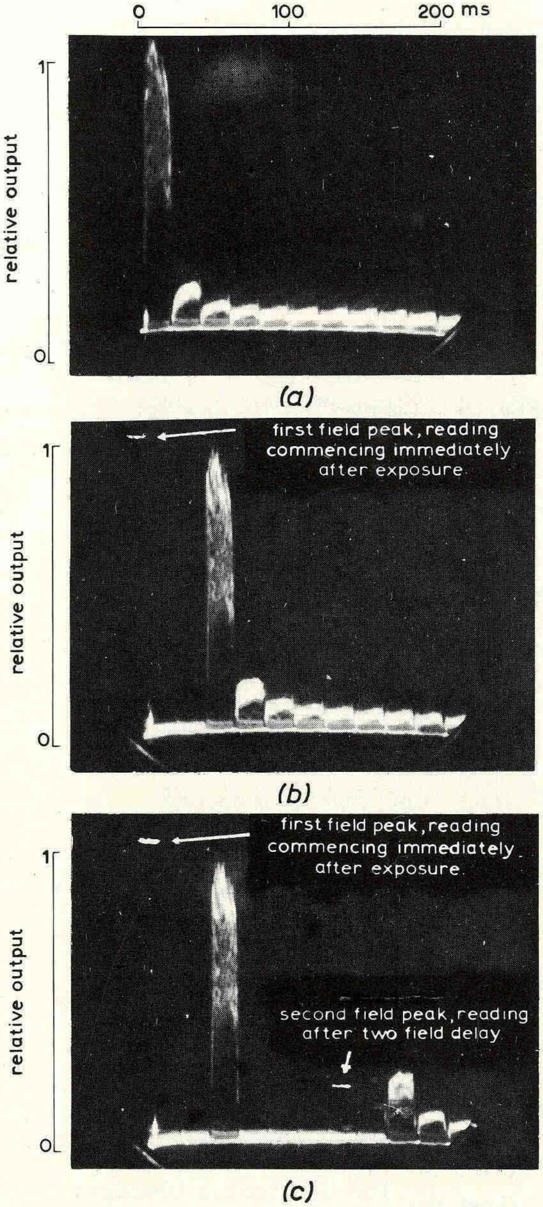


Fig. 8 - Storage loss effect, showing increased second scan output when delayed with respect to first scan

(a) Reading immediately after exposure

(b) Reading delayed by two fields. First field peak of (a) is shown.

(c) First reading delayed by two fields. Second reading delayed for five fields after first. First field peak of (a) is shown and second field peak of (b) is shown.

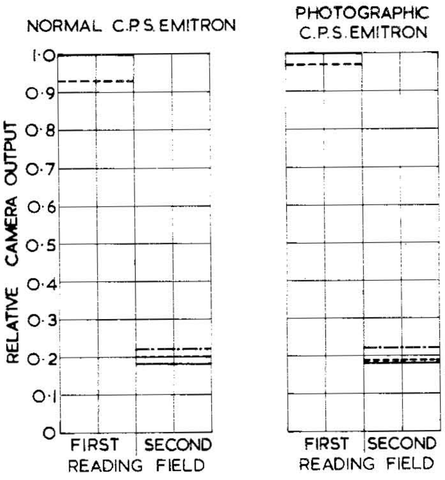


Fig. 9 - Comparison of storage characteristics of normal and photographic C.P.S. Emitrons

—— 1st reading field immediately after writing. 2nd reading field immediately after 1st.

---- 1st reading field delayed by two fields after writing, 2nd reading field immediately after 1st.

-·-·- 1st reading field delayed two fields after writing, 2nd reading field delayed five fields after 1st

2.4. Horizontal Resolution

In order to measure the effects of storage, illumination level and exposure time upon horizontal resolution, measurements were made in three different conditions:

(i) with various storage periods;

(ii) with various illumination levels and short exposure;

(iii) with various illumination levels and continual exposure.

The arrangement of apparatus used is shown in Fig. 10. A short persistence cathode-ray tube displaying an undeflected defocused spot was used as the light source, and the cathode-ray tube beam current was either maintained at a constant value or switched on for an adjustable period at the start of a 16-field cycle. The peak brightness of the defocused spot was fixed and the camera-target illumination was controlled by neutral-density filters positioned in front of the display cathode-ray tube. The defocused spot illuminated a circular area approximately 16 picture elements in diameter, into which three different grating patterns could be placed; the grating patterns consisted of alternative opaque and transparent vertical stripes having dimensions corresponding to 494, 163, and 41 elements per picture width respectively.

Sequential 180-line scanning was used for the camera tube and a line-selecting waveform monitor was arranged to display, during the first reading field, a line centrally situated within the image of the grating. The grating patterns produced output signals having frequencies of 2·6, 0·866 and 0·22 Mc/s.

An E.E.L. cell photometer and a photomultiplier tube were used to measure the camera illumination under steady-state and pulse conditions respectively.

2.4.1. Horizontal Resolution with Storage

The horizontal resolution, as a function of a storage period varying from zero to 6 fields, was measured using the different grating patterns and the same illumination level; an exposure of 10 ms was used, and the illumination was set to give a standard output using the coarsest pattern.

The graph, Fig. 11, shows that without a significant period of storage, the modulation depth falls to 16% for the finest pattern; this is due mainly to the scanning-beam aperture and, to a much smaller extent, to the camera lens. In these experiments, percentage modulation $M = (A - B)/(A + B) \times 100$ was calculated from the expression where A was the maximum value and B the minimum value of the camera output (referred to its output at black).

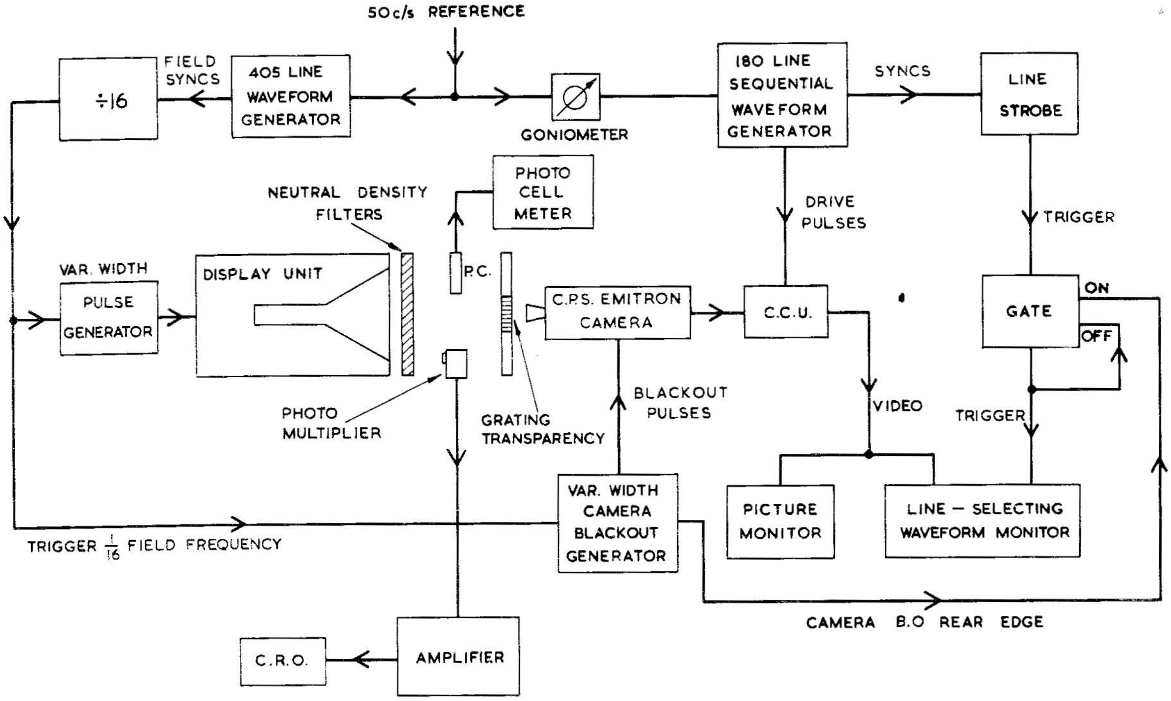


Fig. 10 - Apparatus used for measurement of C.P.S. Emitron horizontal resolution characteristics

From Fig. 12(a) and 12(b), a comparison can be made between the camera signals obtained using a 2·6 Mc/s pattern, on the one hand with immediate reading and on the other hand after a storage period of 6 fields. The photographs show that, with storage, there is a fall in the mean level of the output and, to a slightly smaller extent, in the value of $(A - B)$. In Fig. 13, the results obtained with the various patterns are shown, and it is seen that, as the storage time is increased, there is an apparent increase in modulation depth for the finer patterns; this is caused by the increased ratio of $(A - B)$ to the mean level of the signal.

The mechanism of this phenomenon is not understood and could only be resolved by further, and more detailed, investigations outside the scope of this report.

2.4.2. Horizontal Resolution with Various Illumination Levels and Short Exposure

In this experiment, the grating pattern corresponding to 2·6 Mc/s was used and reading took place immediately after exposure; the exposure had a duration of 100 μs and occurred every 16 fields. The resolution was then measured with different amounts of illumination up to a level producing full signal output from the camera.

The results are shown on the graph, Fig. 14, and it is immediately seen that there is a steady decrease in resolution with increasing illumination. Over the normal contrast range, the modulation drops by about 15% as the illumination is increased from about one third the full illumination to the full value. This loss of

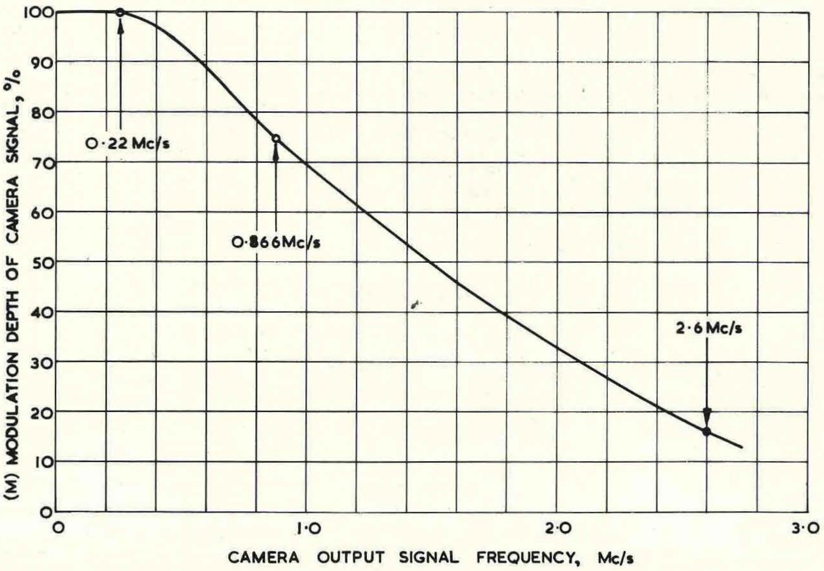


Fig. 11 - Modulation depth of camera signal as a function of frequency, exposure time 10 ms, reading immediately following exposure

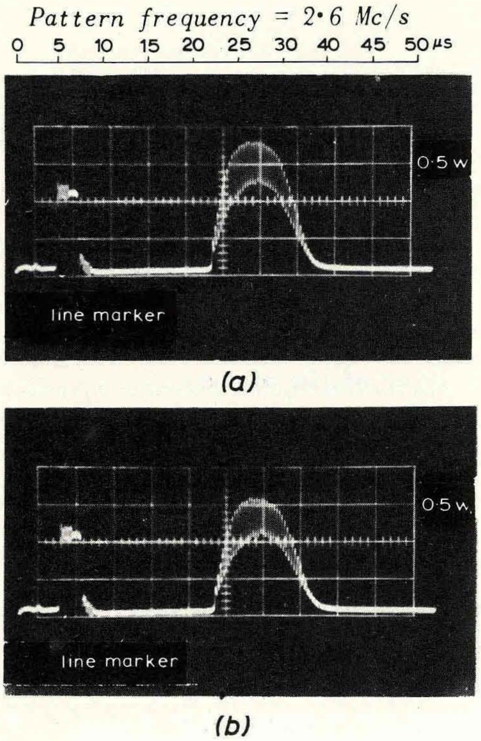


Fig. 12 - Horizontal resolution as a function of storage. Exposure time 10 ms

(a) Reading immediately after exposure

(b) Reading delayed 6 field periods after exposure

resolution is possibly due to the fact that, at high illumination levels, a greater proportion of the scanning beam is used to discharge the target, thus resulting in an increase in the effective beam aperture.

2.4.3. Horizontal Resolution with Various Illumination Levels and Continual Exposure

In order to compare the performance of a C.P.S. Emitron under normal conditions (i.e., with continuous illumination) with that obtained with short exposures, a further series of measurements was made using the defocused spot on the display tube as a continuous source of light illuminating the 2·6 Mc/s grating pattern.

The results are shown in Fig. 15 and are similar to those obtained in the previous experiment to the extent that modulation depth decreases with increasing image brightness. There is, however, a general increase in the modulation depth which can also be seen from a comparison of the oscillograms in Fig. 16; these show the results obtained using the 2·6 Mc/s pattern, with brief and continual illumination.

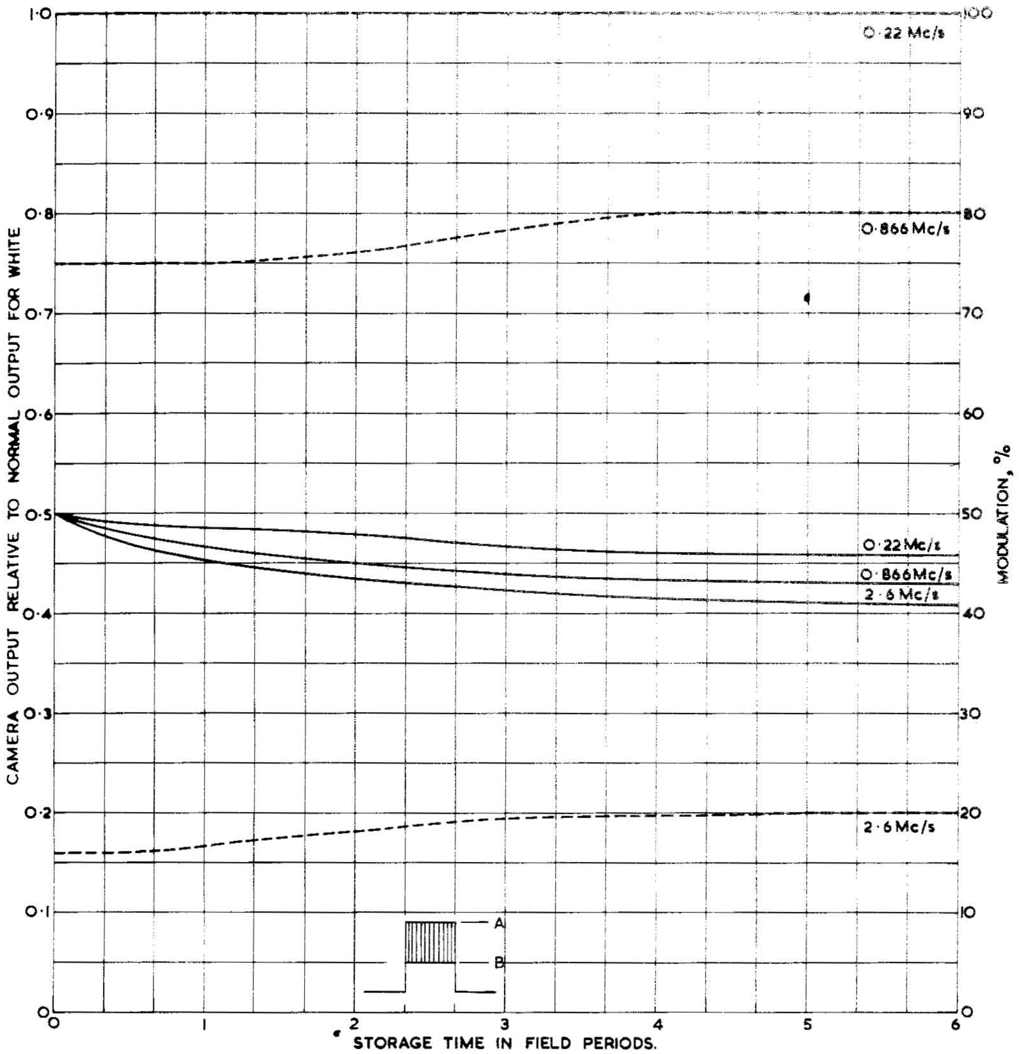


Fig. 13 - Horizontal resolution as a function of storage time.
Exposure time 10 ms

---- Modulation, %
—— Mean value

This effect may be caused by reciprocity failure of the C.P.S. Emitron occurring with very brief exposures. Reciprocity failure is the inability of the camera to maintain the same output signal when both the illumination and exposure time are varied in such a manner that the product of these two factors remains constant.

2.5. The Relationship Between Illumination and Exposure Time

In order to determine whether the C.P.S. Emitron suffers from reciprocity failure (as defined in Section 2.4.3.) the relationship between illumination and exposure time, for a constant output, was investigated.

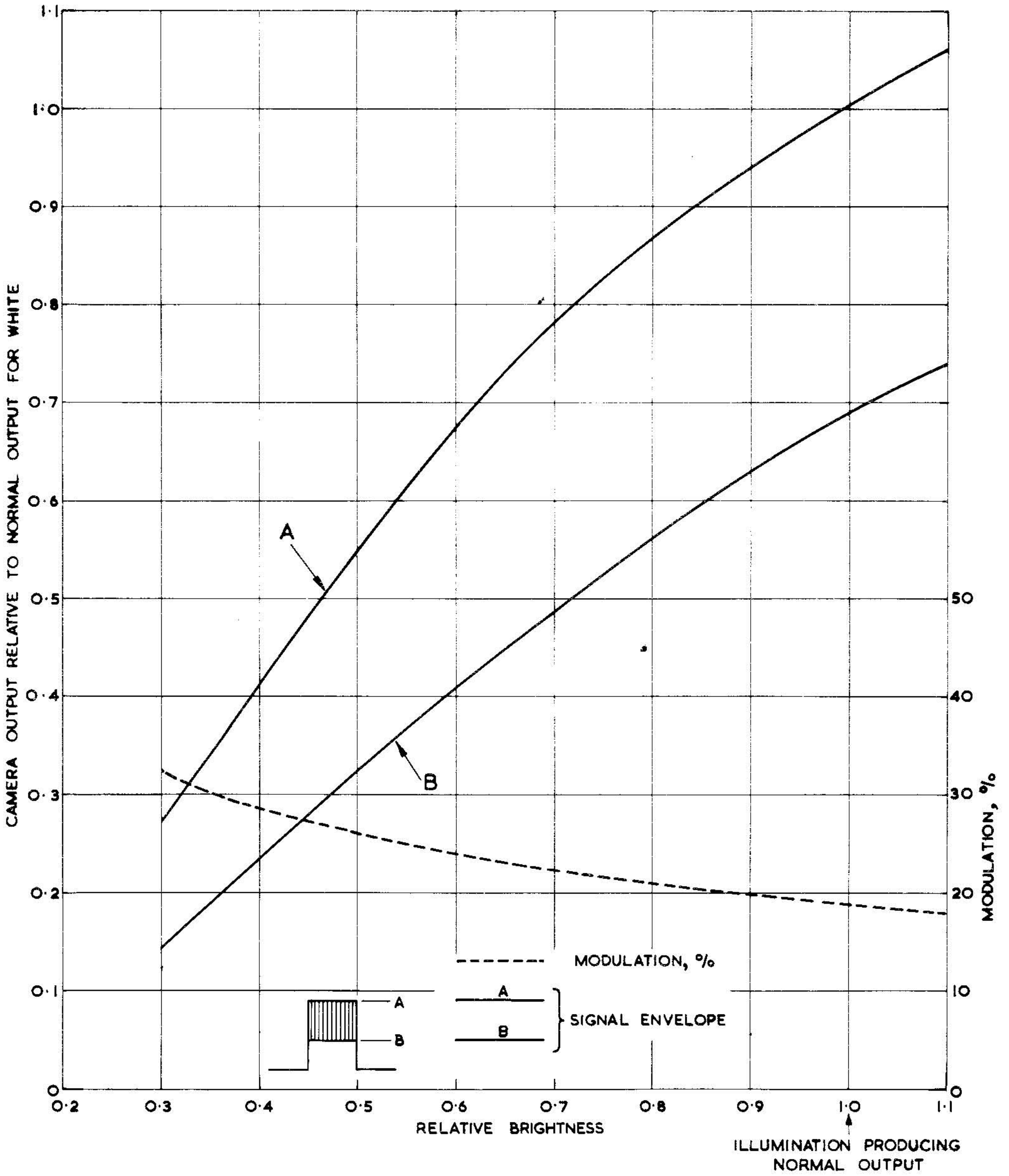


Fig. 14 - Horizontal resolution as a function of brightness, 2·6 Mc/s signal, exposure time 100 μs/16 fields. Read immediately after write

The same arrangement of apparatus was used as in the experiment described in Section 2.4.2., with the exception that the camera tube was arranged to view a small uniformly illuminated area of the cathode-ray tube screen. In this case the illumination was varied and the exposure time was correspondingly modified so that the product of illumination level and exposure time was constant.

Measurements of the camera output signal corresponding to a selected line passing through the centre of the test image were then taken for exposure times ranging from 3 μs to 17 ms. As the illumination level was reduced, the exposure time, which could be varied continuously, was increased so that the product of illumination

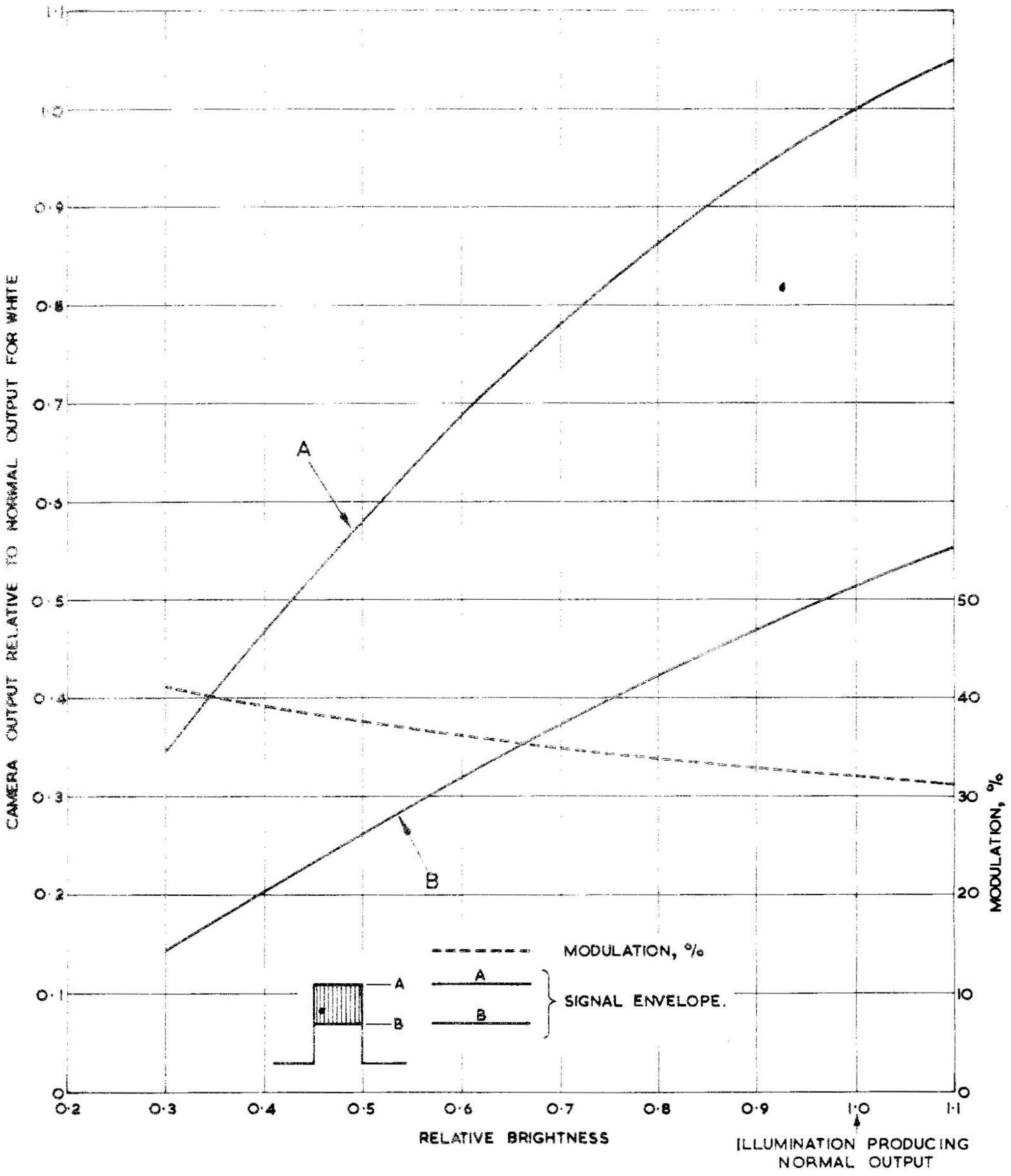


Fig. 15 - Horizontal resolution as a function of brightness, 2·6 Mc/s signal, continuous illumination

and exposure time, as indicated by the integral of the output pulse from the monitoring photomultiplier, remained constant. The illumination-level changes involved covered a range of 6000 : 1, and it was found necessary to reduce the photomultiplier sensitivity by means of neutral-density filters so as to accommodate this range without overloading. As the exposure time was varied, the camera-blackout duration was adjusted so as to inhibit the camera scanning beam throughout the exposure and in order to provide reading immediately following exposure.

The results are shown graphically in Fig. 17 and they indicate a 17% increase in camera output for an exposure time of 17 ms compared with that obtained for the

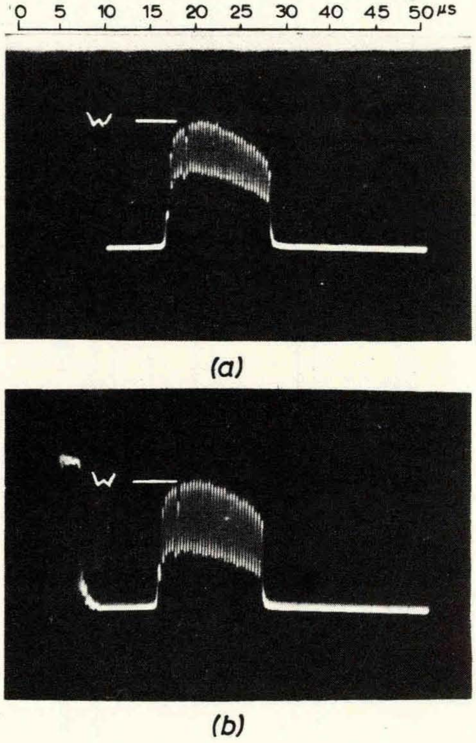


Fig. 16 - Modulation depth with brief and continued illumination. 2·6 Mc/s pattern

(a) Exposure time = 100 μs
(b) Continual illumination

shortest time of 3·5 μs, the illumination being varied accordingly. Thus, there is evidence of slight reciprocity failure, most of which occurs between 1 and 17 ms; the results obtained for very brief exposures should be regarded as being somewhat unreliable owing to the limited accuracy of the measurements at these exposures.

2.6. Beam Pulling

The erasure experiments showed some evidence of 'beam pulling', which is the tendency of the scanning beam to be deflected from its correct path towards target areas carrying relatively large positive charge and it is caused by the transverse electric fields due to these charged areas. It results in the distortion of bright image boundaries so as to produce an apparent enlargement of the image together with a loss of resolution. Beam pulling includes other effects such as changes of the beam aperture shape in the presence of charge transitions on the target.

Beam pulling in C.P.S. Emitrons[2] and other types of camera tube has been discussed qualitatively elsewhere.[6,7,8] The following experiments were carried out in order to obtain quantitative measurements of the effect in the C.P.S. Emitron.

In the first set of experiments, devised to investigate the effect of vertical beam pulling, the scanning raster was shifted by small known amounts in a vertical direction, the test image consisting of a chequer-board pattern. The pattern was aligned horizontally with the scanning lines and the signal on a particular line was examined as that line approached and crossed both black/white and white/black image transitions. This test was repeated using different illumination levels and a measurement of beam pulling was obtained from a graphical interpretation of the results.

An obvious difficulty encountered in this procedure is concerned with establishing a reliable reference corresponding to the actual position of a boundary on the target, but, as the measurements taken at relatively low illumination levels showed little change of location for transitions in either direction (i.e., when beam pulling was negligible and the beam aperture was a minimum), this enabled an approximation to the true position of the transition to be established.

Part of the chequer-board transparency was focused on to the centre area of the target and the camera control unit was modified so as to include a vernier field-shift control calibrated in 1/5th line-spacing intervals; 180-line sequential scanning was employed. A block schematic diagram, Fig. 18, shows the arrangement of the apparatus, which includes a line-selecting waveform monitor for camera-signal measurements. The transparency illumination was varied by means of a Variac.

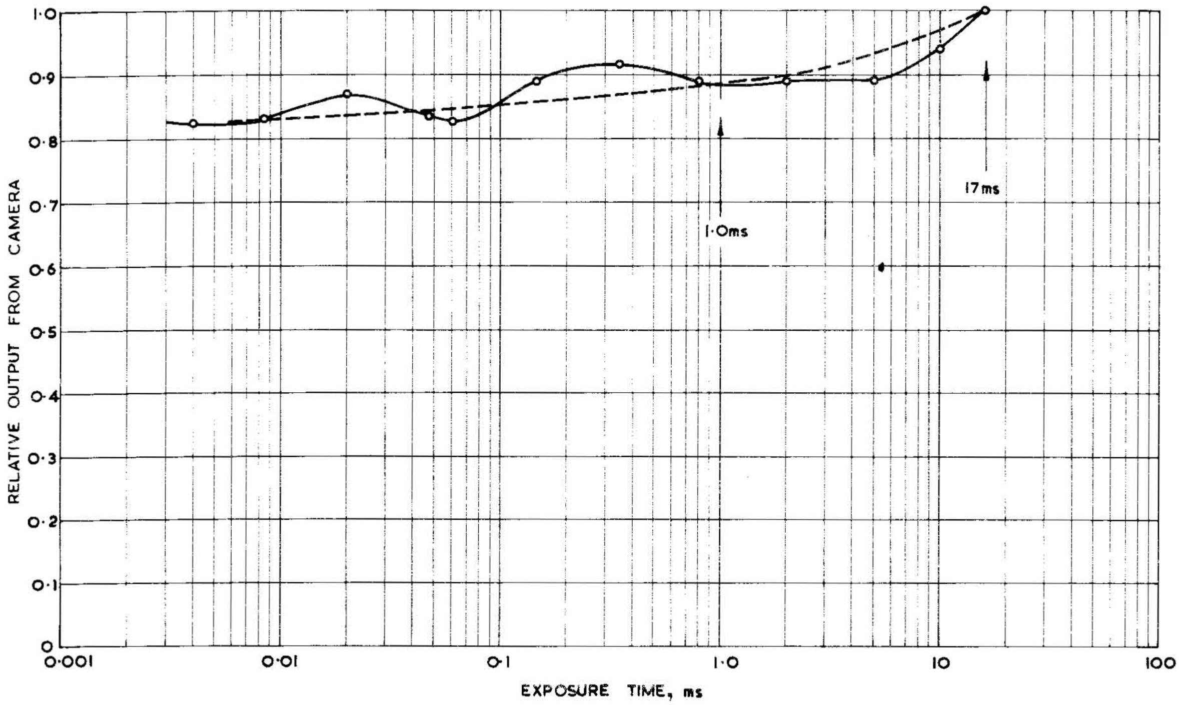


Fig. 17 - The relationship between illumination and exposure time

A scanning line close to a horizontal boundary of the image was selected and moved towards the transition by means of the vernier field-shift control until a change in the signal was seen in those portions of the scanning line that were previously producing a signal corresponding to black. The transparency was then rotated slightly until approximately equal signals were obtained in the 'black' portions of the scanning line; the scanning line was then assumed to be parallel to the horizontal boundaries on the chequer board.

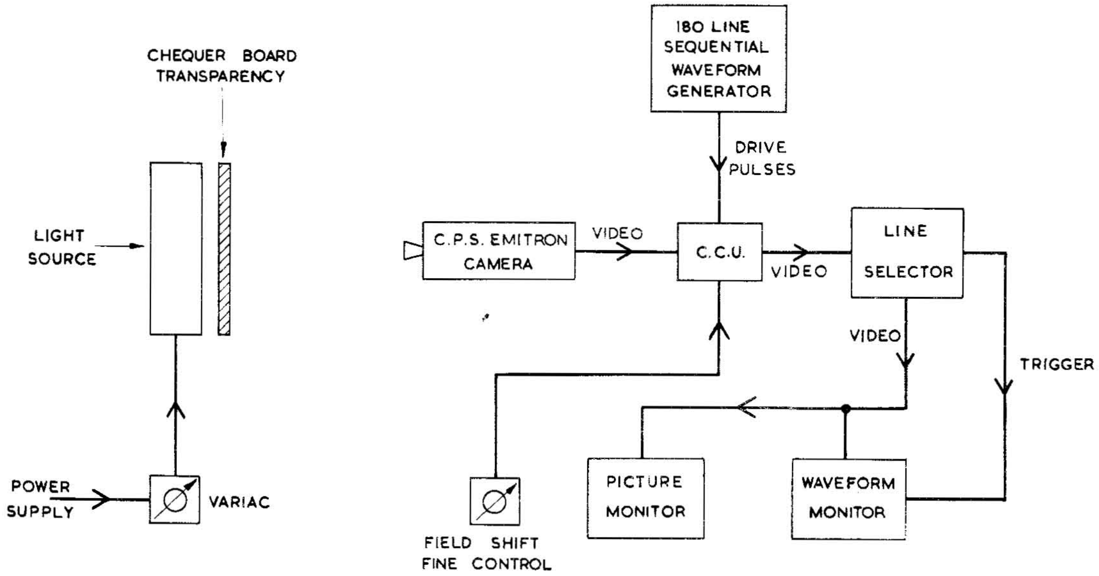


Fig. 18 - Apparatus used for measurement of C.P.S. Emitron beam-pulling effect

The chosen scanning line was then moved away from the boundary until no signal was present in those portions of the line which corresponded to black. Thus the signal, during the selected line, approximated to a square wave having a peak value corresponding to white. The transparency illumination was then reduced until only a very small output signal was obtained. The scanning line was then moved towards the boundary in steps of 1/5th line spacing and readings were taken at those points along the line corresponding to both a black and a white square of the image; this was continued until the boundary had been crossed. Thus simultaneous measurements of beam pulling were made for black-to-white and white-to-black transitions.

This procedure was repeated with increasing levels of illumination up to a value corresponding to white.

A corresponding set of measurements was then made in the line direction, the low-pass filter in the camera output having been removed from circuit. Measurements were taken, along a line crossing a vertical black-to-white boundary, at intervals of 0·2 μs using a calibrated oscilloscope for the measurement of time. Further measurements were then taken at the same points along a line crossing a white-to-black boundary.

Beam-pulling effects associated with a sharp corner were next examined. A uniformly illuminated square area was used as the test object and it was positioned so that its image occupied the bottom right-hand quarter of the camera-target area, care being taken to ensure that the top horizontal edge of the target was parallel with the scanning lines. Then, by a combination of the methods used previously for measuring beam pulling in both the line and field directions, a series of readings was obtained, corresponding to sections, taken in the line direction at vertical intervals of 1/5th of line spacing, through the corner transition. Two series of measurements were obtained with camera-output levels corresponding to white (100%) and near-black (10%).

The results of the various sets of measurements, taken in both the field and line directions, are shown graphically in Figs. 19 and 20. In Fig. 19, the results for low-level illumination produce curves that are similar in shape for transitions both from black-to-grey and vice versa, and this indicates that beam pulling is negligible at these brightness levels. Thus the position of the transition has been assumed to be at the coincident half-amplitude points on the curves obtained for black-to-grey and grey-to-black transitions. At higher brightness levels the curves for horizontal black-to-white and white-to-black boundaries are neither symmetrical about the transitions themselves, nor about their own half-amplitude points. As the maximum target illumination is increased to a value slightly beyond that corresponding to white, a horizontal boundary appears to move upwards by a distance of approximately 1/200th of the picture height. Similarly, from Fig. 20, vertical black-to-white and white-to-black boundaries appear to move to the left by about the same amount.

White-to-black transitions suffer severe sharpness degradation in both the line and field directions. Upon approaching a white-to-black transition, the beam is decelerated; this results in a reduction of the sharpness of the signal corresponding to the transition. However, the beam is accelerated as it crosses a black-to-white transition and thus discharges the target ahead of its intended position.

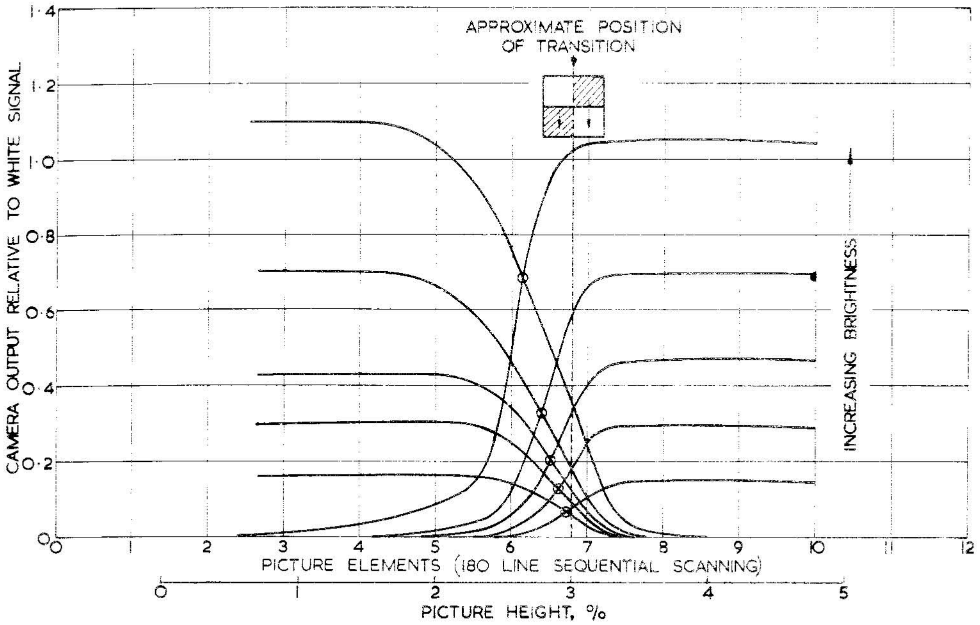


Fig. 19 - Beam-pulling effect in field direction, changes in output level over part of a selected line through horizontal black/white and white/black transitions: 180-line sequential scanning

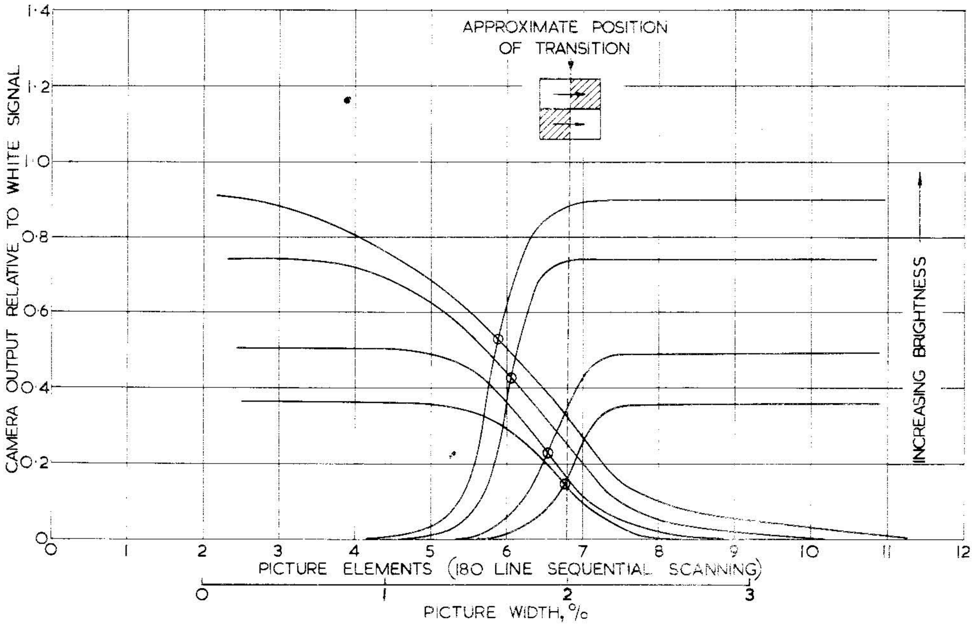


Fig. 20 - Beam-pulling effect in line direction, changes in output level over part of a selected line through vertical black/white and white/black transitions: 180-line sequential scanning

A further factor, that is said to contribute[2] to the rounding of a white-to-black transition, is concerned with the emission of secondary electrons from the scanned point on the target; no evidence of this effect was found in the experiments described here.

The curves for transitions from black-to-white and vice versa in both the field and line directions, have considerable 'toes' extending into black areas. These are thought to be due to both beam pulling and the effects of inter-element capacitances causing charge to appear in target elements immediately adjacent to highly charged areas, as described by Theile.[7]

From the results of the 'corner' measurements, a series of voltage contours was developed corresponding to the corner of the illuminated square image on the target. The contours of the half-amplitude values of transitions from black-to-white and from black-to-grey are shown in Fig. 21, which is drawn as a plan view of the target and illustrates the approximate position of the charge-image on the target.

The extent by which the edges of a bright image apparently move is clearly seen to be about two picture elements when expressed in terms of 405-line interlaced scanning. A rounding of the corner is seen to occur at low brightnesses (approximately 10% of white) and is essentially due to beam-aperture distortion. With high image brightness (white) considerable displacement of the sides of the square occurs, but there is very little displacement of the corner position. This is the result of both an increase in aperture distortion, due to a greater beam diameter, and a reduction in beam pulling near the corner, where the potential gradient is steeper than elsewhere. Near the corner, the beam is required to approach the image boundary more closely before being pulled to the same extent.

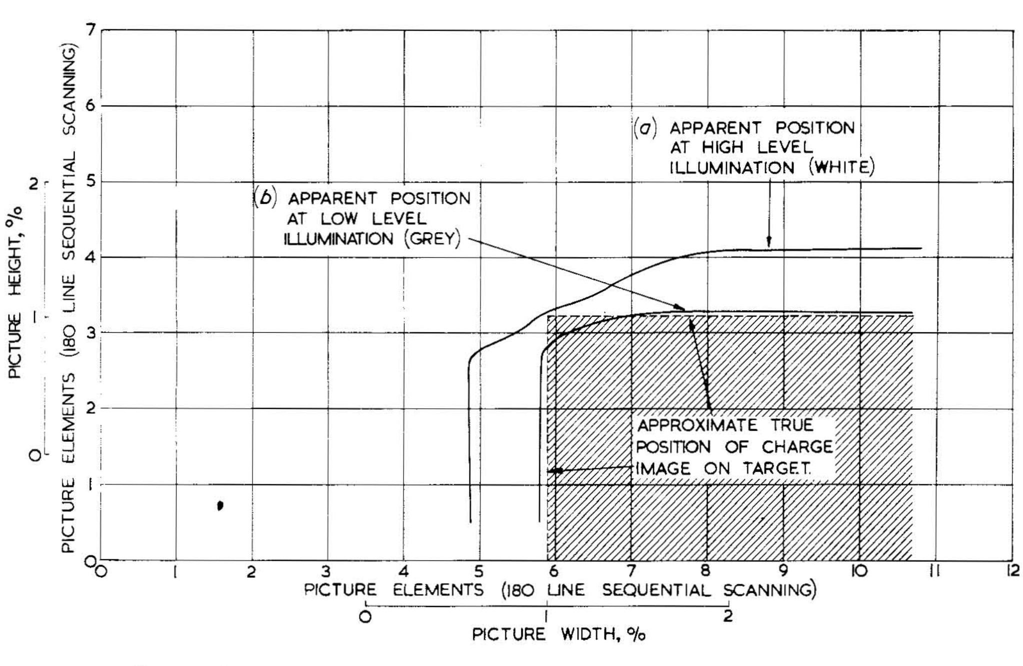


Fig. 21 - The effect of beam-pulling on a corner boundary showing the apparent positions of bright and dark images: 180-line sequential scanning

It is interesting to note the effect of beam pulling on a test pattern of broad vertical black-and-white bars having 25 cycles/picture width, as shown in an oscillogram. Fig. 22 represents a signal derived from such a pattern and shows the sharpness degradation suffered by the rear edges of the white bars; the amplitude differences of the individual bars is due to uneven illumination of the test pattern.

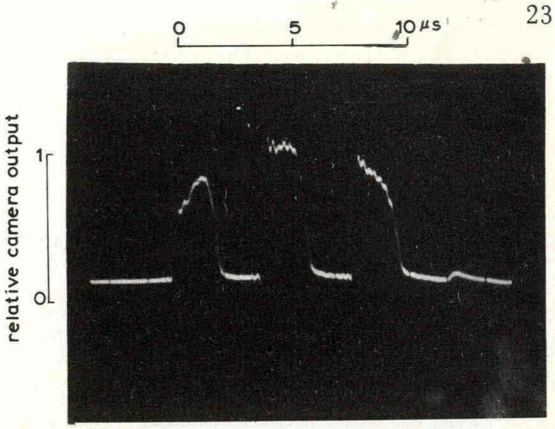


Fig. 22 - The effect of beam-pulling on the rear edges of white bars: scanning direction, left to right

2.6.1. Beam-Pulling Measurement Using a Wedge

Another method of measuring beam pulling was used, which requires less complicated apparatus. The test object consisted of an illuminated 'acute angle' wedge having the bisector of its apex lying parallel to the scanning lines.

The principle of this method of measurement is described with reference to Fig. 23. At low illumination levels, where there is a negligible beam-pulling effect, the camera-output signals corresponding to a pair of scanning lines (dashed lines in the figure), one from the top and the other from the bottom of the wedge (see Fig. 23) were displayed on a waveform monitor and the positions of the two signal transitions made coincident, on the monitor trace, by adjustment of the camera-tube vertical shift control. As the illumination was increased, beam pulling became evident and the scanning spot was displaced downwards, within the target area corresponding to the illuminated wedge, towards the unscanned, charged area of the target. From Fig. 23 it will be seen that, when deflected downwards, the upper scanning line crossed the wedge boundary in a direction nearer to the normal than when undeflected; on the other hand, the lower line, after deflection downwards, crossed the wedge boundary in a direction which was less close to normal. Thus, in the case of the upper line, the scanning spot remained within the illuminated area for a longer time than it did when following the lower line. The change in the relative timing of the signal transitions provided a direction indication of beam pulling.

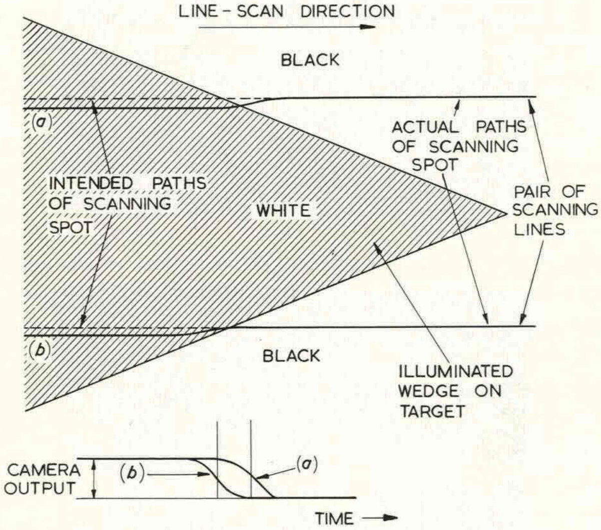
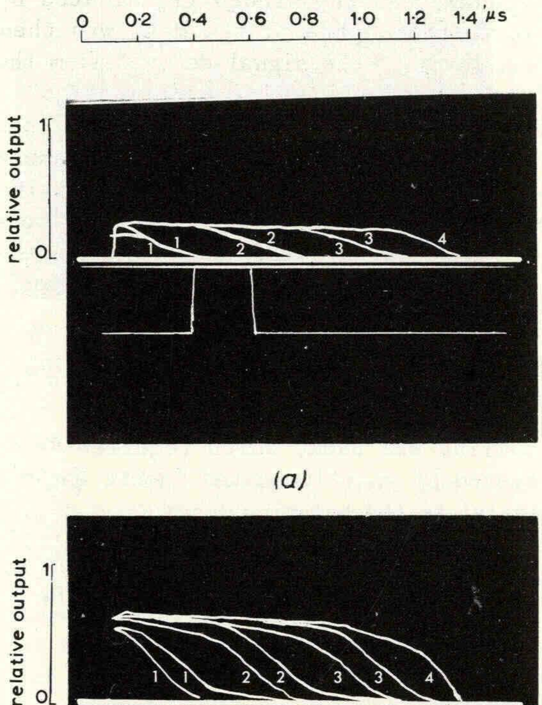

LINE-SCAN DIRECTION
BLACK
(a)
ACTUAL PATHS OF SCANNING SPOT
INTENDED PATHS OF SCANNING SPOT
WHITE
PAIR OF SCANNING LINES
(b)
BLACK
ILLUMINATED WEDGE ON TARGET
CAMERA OUTPUT
(b)
(a)
TIME

Fig. 23 - Beam-pulling measurement using a wedge

A series of oscillograms, Fig. 24, shows some results obtained by this method. A low level of wedge illumination was used for Fig. 24(a), an intermediate level was used for Fig. 24(b), and white level was used for Fig. 24(c). It will be seen that as the illumination was increased, the apparent position of the upper wedge



The figures indicate the corresponding lines of each pair

(a)

(b)

(c)

Fig. 24 - Beam-pulling measurement using a wedge; oscillograms

(a) Low illumination; lines paired
(b) Increased illumination; lines separating
(c) High illumination; increased separation of lines

boundary was displaced to the right in comparison with its counterpart at the bottom of the wedge. One scanning line was arranged to pass through the apex of the wedge (trace No. 4). The signal produced during this line was reduced in amplitude as the previous scanning line (one of the pair labelled 3) encroached on the strip normally occupied by the 'apex' line; this is most apparent in Fig. 24(c). The amount of beam pulling at white level, measured by this method, was approximately two picture elements (in terms of the 405-line interlaced standard), which agrees with the results obtained in the previous experiments.

This 'wedge' method of measuring beam pulling, while not providing such a comprehensive picture of beam-bending effects as the previous method, provides a simple and effective method of assessment.

2.7. Flare and Veiling-Glare Measurement

Flare and veiling-glare are defined here as unwanted signals produced from one part of the target as a result of an object imaged upon another part. Such signals can be produced by internal optical reflection, particularly from the face-plate of the camera tube. However, another unwanted signal of similar form is caused by positive ions, produced by the scanning beam, landing on the target to give an effect described here as 'ion fogging' (see Section 2.8.).

The total signal arising from flare, veiling glare and 'ion fogging' in a C.P.S. Emitron was measured and, in order to separate the contributions from optical and electronic sources, the optical flare was measured independently.

In order to measure the combined spurious signal, a standard method, described by Hacking and Sproson[9] for the measurement of flare produced in lenses, was adapted for the problem.

A small square mask of blackened copper representing 1/200th of the target surface-area was fixed at the centre of the camera-tube window, and the window illuminated by collimated light. The signal corresponding to the centre of the mask was then measured and expressed as a fraction of the mean level of the signal derived from the surrounding areas. The level and the angle of incidence of the illumination on the target were varied in an attempt to establish whether the flare was proportional to illumination and also whether additional flare would be produced in the camera tube when used with a lens. The collimated light was produced by a lamp having a small filament, placed 150 cm from the far end of a long tube positioned in front of the camera tube; the tube was 8 cm in diameter and a further 150 cm in length. The interior of the tube was blackened and fitted with a number of light traps suitably spaced, so as to reduce the effects of any internal reflections within the tube itself.

The camera was scanned, as normally, according to the 405-line standard and a line-selecting waveform monitor was used to display a line passing through the centre of the black 'patch' corresponding to the copper mask. A pulse generated by the selector unit was used to switch-off the camera beam-current for approximately 4 μs during the active line period. This gave a true black reference-level displayed alongside the black signal from the patch. As the flare signal was comparatively small in amplitude, a high-gain amplifier was included in the feed to the oscilloscope; a low-pass filter was included in the circuit in order to restrict the effect of random fluctuation noise.

Measurements were taken of the signal amplitudes corresponding to the centre of the patch and the area surrounding the patch. A total of six readings were taken using three angles of incidence (normal and ± 13°) in the horizontal plane, and two illumination levels (50% and 100% of white level). A number of C.P.S. Emitron tubes was measured in this way and in each case care was taken to illuminate the target as evenly as possible.

Fig. 25(a) shows an oscillogram of a selected line passing through the centre of the patch and illustrates the signals corresponding to the patch and the reference-black signal caused by the injected marker pulse. The results of measurements using five C.P.S. Emitron tubes yielded spurious signal values lying between 2% and 4·5%. The measurements taken with the collimated light at other than normal incidence did not show the expected increase in spurious signal, but errors in measurement may have masked such changes; despite the use of a low-pass filter in the signal path, measurement accuracy was limited by the unfavourable ratio of flare signal to noise level.

The percentage of spurious signal did not appear to vary with illumination, which seemed to indicate that the cause was largely optical. However, an independent measurement* of optical flare and veiling glare in the tube showed that such causes would only account for a spurious signal of <1%.

2.8. Ion Fogging

It would seem, therefore, that most of the spurious signal was electronic in origin. It was noticed, however, that when beam current was increased above the normal level, the spurious signal increased rapidly; a moderate increase of beam

* This measurement was made by Hacking

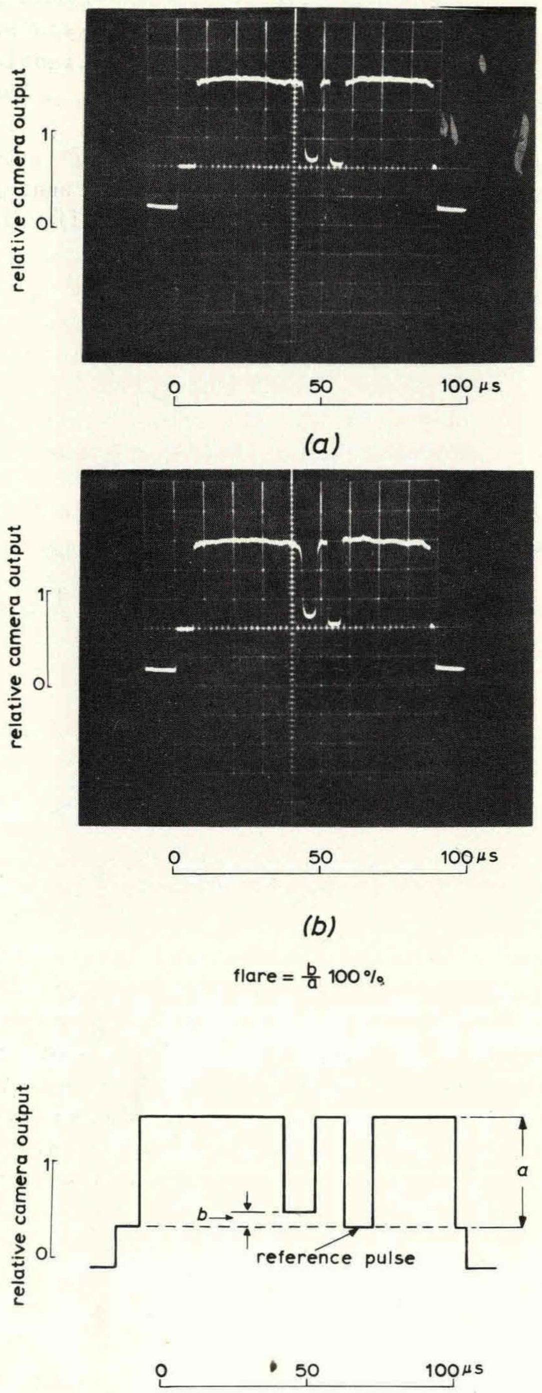


Fig. 25 - C.P.S. Emitron flare measurement

(a) Normal beam current flare approximately 4%

(b) Increased beam current flare approximately 8%

current produced a spurious signal level of 8% as shown in Fig. 25(b), while a further increase in beam current produced even higher levels of spurious signal. The rapid increase of spurious signal with beam current could be taken as a sign that the beam current was excessive. Such spurious signals produced by other than optical causes could result from the presence of positive ions in the tube. The operation of the camera-tube ion-trap mesh, which is described in detail elsewhere,[1] ensures that any positive ions produced near the target are fairly uniformly distributed over the target. These ions, nevertheless, tend to land on uncharged areas of the mosaic, which are then discharged by the scanning beam in the normal manner. An increase in beam current produces an increase in the number of positive ions and hence an increase in signal current. It was found that, when the illumination of the C.P.S. Emitron was cut off, a small output signal was present; this signal could be increased by increasing the beam current.

Thus it would seem that the amount of this 'ion-fogging' in a C.P.S. Emitron is largely a function of beam current and that by economical use of the beam, the level of 'ion-fog' signal relative to that of white, can be kept below approximately 4%.

3. DISCUSSIONS OF RESULTS

The experiments concerned with target erasure show that the combined effects of beam pulling and beam aperture prevent the recovery of independent signals from the odd and even fields of a 405-line interlaced raster. Thus the majority of the charge existing on the target is erased during each field scan, consequently reducing the maximum exposure time of the camera tube. As the number of scanning lines is reduced, the amount of interaction between successive scans decreases, the beam then being diverted towards unscanned charged areas on the target.

After a single exposure, the majority of the target charge is removed during the first scan, the remainder of the charge being erased during successive scans. The signals produced during these scans may be due to a combination of lag signals and contributions from adjacent unscanned elements resulting from beam pulling. Lag signals, caused by the failure of the beam to erase target charge completely, are a function of the beam-acceptance characteristics of the target and are discussed by Meltzer and Holmes.[6] It would seem, however, that with approximately 200 scanning lines per field, the discharge lag for a particular picture element would be difficult to assess because of beam pulling.

The results of the experiments also reveal sensitivity variations over the target that would add a certain amount of spurious 'background' to the camera output signal. In a standards converter of the wide-range type,[3] employing a reference stripe near one vertical edge of the target, the corresponding reference signal may contain error signals due to these sensitivity variations, resulting in a further addition of spurious 'background' to the converted signal.

While the majority of the storage losses would seem to be due to dielectric hysteresis, some of the losses appear to be due to charge spreading to the insulated strips between adjacent elements. The total loss in signal, even after a considerable storage period, does not exceed approximately 10%, unless the operating temperature of the camera tube is increased.

The effect of beam aperture and beam pulling is seen to reduce the vertical resolution considerably and, although lateral leakage of charge to insulated areas of the target is not an important factor in the loss of vertical resolution, it may result in some loss of horizontal resolution with storage. This effect does occur to a small extent, but the mean level of a high-frequency signal decreases more rapidly than does the signal excursion corresponding to the test grating pattern and thus results in an apparent increase in the depth of modulation.

The loss of vertical and horizontal resolution with increased image brightness is to be expected, as the beam aperture will be modified by the demands of the target (i.e., the scanning-beam spot size increases over those parts of the target surface carrying high charge). In addition, the effects of beam pulling reduce both the vertical and horizontal resolution, particularly when the beam is scanning over a white-to-black edge. There also appears to be loss of resolution associated with brief exposures and this could be a result of reciprocity failure; some evidence for this is found in the results of the reciprocity measurements. It could be expected that the camera output would fall with long exposures, due to storage loss, and this may partly compensate the reciprocity failure occurring with short exposures.

Beam pulling is seen to modify a number of the other characteristics, as previously mentioned. Further, it has a noticeable effect on the edges of high-contrast transitions, producing considerable displacement of the boundaries. It is interesting to note that beam-pulling effects in a C.P.S. Emitron could provide registration problems if this type of tube were used in a colour camera; similar difficulties in connection with the earlier type of 3-inch image-orthicon tube have been discussed by James.[10]

The measurements of flare and veiling glare show that these effects are negligible but reveal that 'ion-fogging', produced by excessive beam current, can reduce the effective contrast range handled by the tube.

Examination of all the results obtained in these experiments suggests that the most significant characteristics of the C.P.S. Emitron likely to influence the performance of an image transfer standards converter are those concerned with erasure, storage and possibly reciprocity failure.

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